THE ROLE OF PHOTOVOLTAIC SOLAR ENERGY IN ENHANCING FOOD SECURITY. THE CASE OF PELELE SOLAR POWERED IRRIGATION SCHEME IN WARD 12 OF GWANDA DISTRICT.

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APPROVAL FORM

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The undersigned certify that they have read and recommended to the Midlands State University for acceptance as a dissertation entitled: the role of Photovoltaic solar energy in enhancing food security. A case of Pelele solar powered irrigation scheme in ward 12 of Gwanda District.

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Submitted in partial fulfilment of the Bachelor of social sciences Honours Degree in Geography and Environmental Studies.

DECLARATION

I declare that this is my own work and material used from other sources to compile this dissertation has been fully acknowledged.

DEDICATION

This dissertation is dedicated to my beloved parents, Mr and Mrs M. J. Ndlovu as well as my brothers and sisters whose concerted efforts, support and encouragement has brought this work to fruition. May Heavens light shine on you always.

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ABSTRACT

Access to reliable and affordable energy is a key lever to enhance sustainable livelihoods and an important prerequisite for agrarian economies in Sub Saharan Africa to address food security challenges faced in the region. Limited and unreliable energy supply mainly from conventional energy sources has been a major impediment to increase agricultural productivity in most irrigation schemes in Zimbabwe. Despite having the best solar radiation levels, little research has been conducted to evaluate the contribution of solar PV energy as an alternative to improve agricultural productivity and food security in Zimbabwe. The study examined the role of solar PV energy in enhancing food security focusing on Pelele solar powered irrigation scheme in ward 12 of Gwanda district. The research provided a broad assessment on the role of solar PV energy in food security at Pelele village to bridge the existing knowledge gap using a case study research design. Data was acquired through the use of questionnaires, interviews, focused group discussions, observations and secondary sources of data. The results of the study revealed that the ample availability of free energy from the sun throughout the year significantly stimulated positive impacts on food security. The impacts included increased food production, cost savings, multiple crops in a year, improved food stability and reduced carbon foot print. The research found that solar PV pumping enhances water availability, consistency and sufficiency to meet crop water requirements which allow for sufficient quantities of food to be produced on a consistent basis. Sustained food production allows farmers to stretch their food stocks for long to eliminate recurrent shocks of drought and seasonal food shortages experienced in the district. The results of the study also established great reliability of solar PV owing to availability and consistent power supply that meets energy demand throughout the year coupled with high durability of solar PV pump. The study further established that the annual total power produced by solar panels at Pelele irrigation was 3520kWh/year which far exceeds annual demand of 1170kWh/year. This showed that the solar PV system is oversized. However the study revealed that the underutilized energy presents a huge potential for energy sharing to power other food security activities such as poultry lighting and refrigeration to reduce post-harvest losses of perishables such as tomatoes. The research concluded that solar PV significantly enhance food security. The study recommends that the ministry of Agriculture, Mechanisation and Irrigation development should partner with NGOs to replace diesel engine pumps with solar PV system on abandoned irrigation schemes in Gwanda district to enhance food security.

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ACRONYMS

FAO	- Food and Agricultural Organisation
PV	-Photovoltaic
DC	-Direct Current
AC	-Alternating Current
SDG	- Sustainable Development Goals
ZIMASSET	- Zimbabwe Agenda for Sustainable Socio Economic Transformation
ZimVAC	-Zimbabwe Vulnerability Assessment Committee
NGO	-Non Governmental Organisation
ZERA	-Zimbabwe Energy Regulatory Authority
REA	-Rural Electrification Agency
IRENA	-International Renewable Energy Agency
Wp	-peak watt
kWh	-kilo watt hour
kW	-kilo watt
AGRITEX	- Agricultural Technical and Extension Services
ZIMSTATS	-Zimbabwe National Statistics Agency
PSH	-peak sunlight hours
NASA	-National Aeronautics and Space Administration of the USA
IPCC	-Intergovernmental Panel on Climate Change

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CHAPTER ONE: INTRODUCTION.

1.1 Background to the study.

Access to reliable and affordable energy is a key lever to enhance sustainable livelihoods and an important prerequisite for agrarian economies in Sub Saharan Africa to address food security challenges. However food production, agricultural enhancements and policies have not been fully integrated with sustainable energy planning to enhance food security for rural communities in the region (Fakir, 2013)

Food security is underpinned by food systems. Food security is the state achieved when food systems operate such that all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2001). According to FAO (2012) energy is closely linked to food security as all dimensions of food security which are availability, access and utilisation are dependent upon energy.
The nature of energy supply into the agri-food system can substantially influence food security. Food security therefore is diminished when the supply of energy is not convenient and reliable. FAO (2012) opines that to meet the growing demand of food, agri-food systems need to be decoupled from high cost fossil fuel energy sources and renewables such as solar photovoltaic technology being considered as sustainable alternatives.

About a third of people in Sub-Saharan Africa are food insecure (FAO, 2012). This is attributed to a number of factors including climate change, poverty and economic collapse. At same time about 600 million of people in Sub Saharan Africa lack access to electricity. Irrigation development is a well-established procedure in semi-arid southern parts of Zimbabwe to reduce heavy reliance on erratic rains and address perennial food security challenges. However limited and unreliable energy access mostly from conventional energy sources is a major impediment to increase agricultural productivity. These shocks have increased the vulnerability of rural farmers to hunger.

According to Cooper et al. (2011) most irrigation schemes dotted around the country since 1980 have been heavily depended upon fossil fuel energy sources (diesel powered engine pumps) for pumping irrigation water. These conventional sources of energy have resulted in a myriad of challenges to small scale irrigating farmers in rural areas. High fuel prices, frequent trips to purchase fuel and high maintenance costs of diesel engines have pushed production costs beyond the means of small scale farmers and reduce the margin to be gained by farmers. Adding to these challenges is also the short life span of diesel engine pumps hindering sustained energy supply for irrigation (Qhadi, 2014). These challenges have resulted in irrigation schemes operating at low capacity and closures of some irrigation schemes due to lack of access to sustainable energy supply.

Renewable energy technologies such as solar PV are now playing a significant role worldwide as an alternative being adopted in rural areas for pumping irrigation water, providing water for community needs and electricity for residential applications. FAO (2012) opines that solar PV enhances access to reliable, affordable and clean modern energy services particularly well suited for remote rural populations to ensure long term reliability of supply. This is augmented by the fact that solar PV is the most localized of all power generating sources as it can be established almost everywhere in the country close to demand points at a relatively low capital scale (Fakir, 2013). The shift to energy smart agrifood systems is a giant stride in improving productivity in the food sector, reduce energy poverty in rural areas and contribute to climate change adaptability and sustainable development.

In India, erratic electricity grid supply and the rising cost of diesel pumping has resulted in crop failures due to insufficient irrigation water, reduction of crop yields and diminishing income for small scale farmers(Shar and Kishore, 2012). This has necessitated a shift to photovoltaic based pumping technologies which have been in use for over two decades now.

The techno- economic performance of these solar PV pumps has been uniformly positive with substantial financial benefits and production yield increases in horticultural gardens and irrigation schemes in India (Tewari, 2012). This is further supported by findings of the research carried out by Qadhi (2014) in Wadi Hadhramount. The study indicates that by using solar PV for water pumping, the amount of US $51 million dollars for diesel fuel is saved by farmers annually. The Indian experience of solar PV pumps in agriculture is being replicated at farmers' field with more than 7000 solar pumps installed in different states of India. Shar and Kishore (2012) asserts that the uptake of this technology in India is fuelled by the subsidies availed to farmers through the ministry of New and Renewable Energy. In Morocco with 300 solar PV powered pumps already installed, solar PV has also contributed immensely to reliable water supply for consumption and agricultural needs in rural areas (Tewari, 2012). Experiences from these countries show insignificant operating costs of solar PV and an increase in agricultural productivity with low carbon foot print.

Despite such potential of solar PV technologies in agriculture, they have not yet been seriously considered in agricultural planning in Zimbabwe nor has the private sector taken an active lead. Studies carried out by Gwamuri and Mhlanga (2013) put much attention of solar PV potential to residential applications limited to lighting, media access, mobile phone charging and electricity access for social institutions and communities in off grid areas . Their research also pointed much on the impact of solar PV in enhancing and supplementing access to electricity for urban dwellers in Zimbabwe. In recent years, a limited but growing number of solar PV projects are implemented for productive uses such as irrigation in rural areas of Zimbabwe.

With the cost of solar PV technologies falling steadily and the price of diesel soaring, solar PV has emerged as an economic feasible idea. This has captured the interest of NGOs to support communities in establishing off grid solar PV powered irrigation schemes. The newly crafted government economic blue print to promote sustainable development, the Zimbabwe Agenda for Sustainable Socio Economic Transformation (ZIMASSET) also recognizes the potential of solar energy to improve the country's food security (ZIMASSET, 2013).

Although solar PV irrigation pumping technologies are scattered around the world, they have not yet achieved large scale- scale dissemination (Porsoski, 1996). The contribution of solar PV to food security has not received much attention. Existing information on the role of solar PV on food security is limited and widely dispersed as it provides only a glimpse of the current and potential of solar PV in enhancing food security in Zimbabwe.

Widely regarded as the missing Millennium Development Goal, access to sustainable energy is a key enabler to productivity and socio economic development. The study seeks to explore the role of solar PV as an alternative for off grid rural areas of Zimbabwe that experience erratic rainfall patterns in enhancing food security through small scale solar powered irrigation schemes.

1.2 Statement of the Problem

Food insecurity continues to be an area of great concern in Gwanda District due to its water scarcity calling for a concerted approach to eliminate compartmentalization and the silo mentality of government departments in crafting food security strategies. Some irrigation schemes and community gardens established to improve food security in the area are no longer functional with some being less productive largely because of lack of steady supply of energy to pump and distribute underground water into the irrigated areas. Solar PV, a renewable and clean modern energy that is particularly well suited for remote rural populations at low capital costs is underutilized in Zimbabwe.

Despite having best solar radiation levels and sunshine days per year, little research has been conducted to evaluate the contribution of solar PV energy in enhancing food security in Zimbabwe. Therefore the existing information only provides a glimpse of the current and future potential of solar PV in enhancing food security in semi-arid southern parts of Zimbabwe. The current status of total installed solar PV pumping systems in irrigation schemes in Zimbabwe is unknown. Studies done by International Renewable Energy Agency (2011) have confined the potential of solar PV energy only to residential applications. Detailed knowledge on the role played by solar PV energy remains limited and widely dispersed. It is against this background that this research aims to bridge the knowledge gap by providing a broad assessment of the contribution of solar PV in food security focusing on Pelele solar powered irrigation scheme.

1.3 Objectives of the Study.

1.3.1 Main Objective

- To assess the role of solar PV energy in enhancing food security at Pelele village in ward 12 of Gwanda District

1.3.2 Specific Objectives

- To identify the impacts of Solar PV on food security
- To determine the reliability of solar PV as an energy source for pumping irrigation water
- To explore the potential of solar PV energy in food security

1.4 Justification.

The plight of chronic food insecurity in Ward 12 has drawn attention to the Ministry of Agriculture, Mechanization and Irrigation Development, Ministry of Health and Child Care and several departments working on food and nutrition services and non-governmental organizations (NGOs). Erratic rains, increased periods of dry spells and the crippling economy of Zimbabwe has worsened this scenario affecting access and availability of food in rural areas of Gwanda district. This study will be used by academics to further research on the contribution of solar PV energy on food security. Food security requires a multi sectoral approach therefore the study will be of great importance to several government departments to eliminate the silo mentality and compartmentalization in crafting policies aimed at eradicating poverty and hunger.

The Ministry of Energy responsible for rural electrification programs will use this study to develop plans and craft policies that promote sustainable energy initiatives such as solar PV to improve access of energy in rural areas that will serve multi purposes for socio economic development. Regulatory authorities such as Zimbabwe Energy Regulatory Authority (ZERA) may also use this study to support sustainable energy development initiatives.

It will be uneconomical and costly for the Rural Electrification Agency to supply power at every community garden or irrigation scheme in remote rural areas through extension of the national electricity grid. Rather it may use this study to work with departments such as Agricultural and Rural Development Authority to establish decentralized solar power plants that will enhance access to renewable energy for productive uses in rural areas.

Sequel to the above, NGOs can also use this study to provide assistance to rural areas of Zimbabwe with solar power equipment to enhance uninterrupted provision of energy for high productivity in irrigation schemes. Students undertaking Geography and Environmental studies will boost their knowledge to fully understand the relationships between energy security and food security in achieving sustainable development goals.

1.5 Description of study area

1.5.1 Physical characteristics

The study is centred in Pelele village in ward 12 of Gwanda south district which lies in agro ecological region V in Zimbabwe which fall under the Savanna climate (Mugandani et al., 2012). The area is located in semi-arid southern parts of Zimbabwe which experiences frequent droughts and dry spells during the growing season putting rain fed agriculture which is main source of livelihood at risk (Cooper et al., 2008). The mean annual temperature ranges are 21-25 degrees Celsius while the average daily maximum temperature varies from 30-34 degrees Celsius during summer to 22-24 degrees Celsius in winter (Meteorological Department, 2010). Gwanda district is the hottest region of Zimbabwe receiving 9, 5 hours of sunshine per day for nine months in a year (Mhaka, 2015).

1.5.2 Socio-Economic Characteristics

Ward 12 comprise of seven villages which are Pelele, Gungwe, Mangweni, Makokwe, Mawaza, Simbuka and Malitlou with a total population of 5096 people and the average size per household is 4.4 (ZIMSTAT, 2013). The irrigation scheme comprise of 30 beneficiaries which include men and women. The area is served by Gungwe business centre which is also the ward centre while the nearest town is Gwanda which is 102km away.

Rain-fed agriculture and livestock production are the main sources of livelihood. The prevailing climatic conditions make the area very vulnerable to perennial droughts and water scarcity (Meteorological Department, 2010) which have exposed thousands of people to food insecurity. A number of NGOs such as Dabane Trust, Pro Africa and World Vision are operating in ward 12. These NGOs have been working on addressing food security and water scarcity challenges through irrigation, nutrition gardens and food aid, borehole drilling and small livestock production. Chronic food insecurity has necessitated the need for irrigation development in this area. Fig 1 shows the map of ward 12 and the location of Pelele solar powered irrigation scheme.

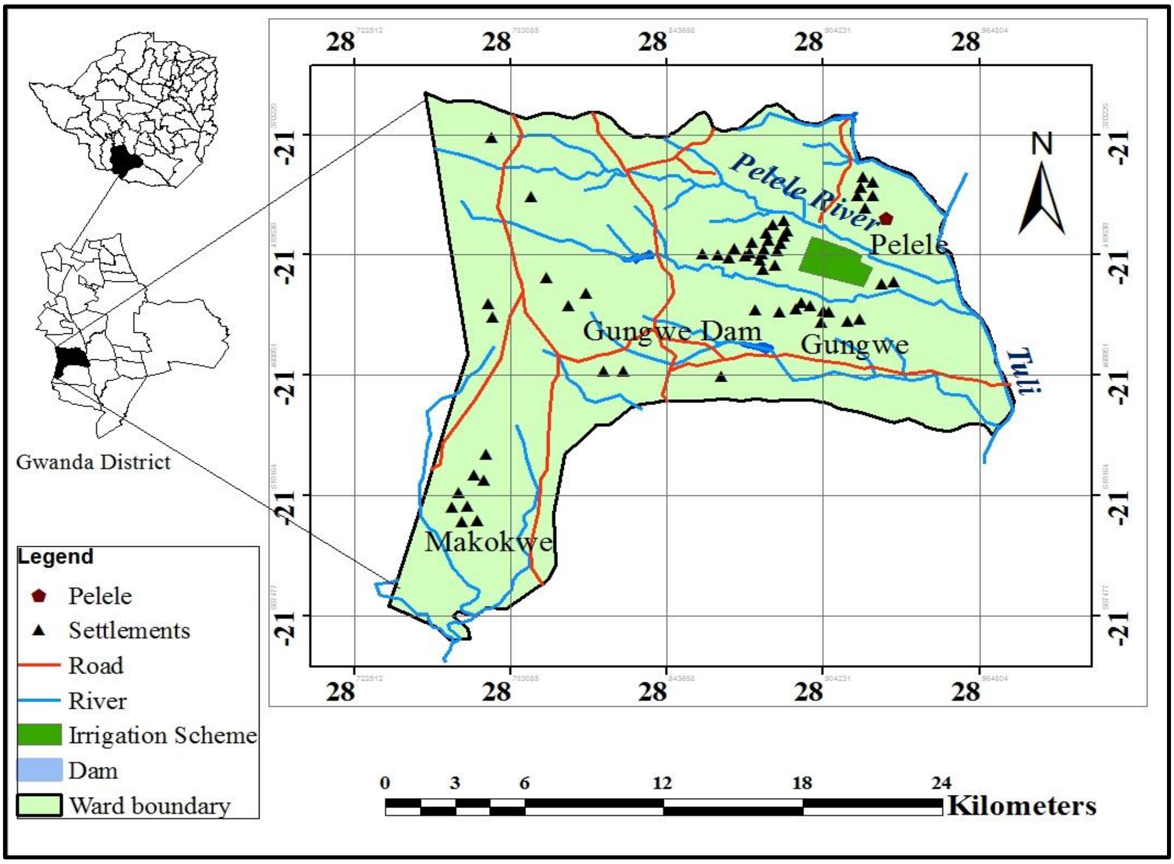

Fig 1 Map of ward 12 showing the location of Pelele irrigation scheme

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter examines literature related to the topic under study. Thus the chapter explores various literature related to the contribution of solar PV as an alternative source of energy for irrigation schemes and its role in enhancing food security in rural communities. The focus of this chapter is also to identify information gaps that may exist in the area under study.

2.1 Definition of Photovoltaic energy

Photovoltaic energy is a technology that converts sunlight into electricity using semi conducting PV cells or solar cells that are composed of semi conducting material, such as silicon, single crystalline thin films or poly crystalline thin films (Practical Action, 2010). PV technology is based on the photo electric effect that was discovered by physicist Edmund Becquerel in 1839. This photo electric or PV effect is the process through which a solar cell converts sunlight which is made up of photons into electricity (Williamson, 2006) According to Boxwell (2014), the heart of solar energy generation is the solar cell. Individual solar cells are assembled into panels or modules of varying capacity. PV modules are often combined to form an array of solar panels. Solar panels are combined either in series to increase voltage or combined in parallel when the application requires an increased current. The amount of electricity output from solar modules depends on its efficiency, its size (surface area) and the intensity of sunlight striking the surface (solar irradiance). According to Gregoire et al. (2013) solar PV is the most promising renewable energy which is capable of satisfying the needs of the remote rural areas as it fits perfectly to the decentralisation of power generation for rural communities due to its localised nature.

2.2 Definition of solar irradiance

The amount of solar power available per unit area is known as irradiance. Solar irradiance is a combination of hours of sunlight and the strength of that sunlight. Williamson (2006) further states that irradiance is a radiometric term for the power of electromagnetic radiation at a surface per unit area. It can be expressed in watts per square metre (W/m^2) or kilowatts per square metre (kW/m^2). Irradiance levels vary with geographical location, seasons and the time of the day. Output from solar panels is dependent upon daily solar irradiance levels.

2.2.1 Solar radiation in Zimbabwe

Zimbabwe is endowed with abundant energy from the sun. According to Mhaka (2015), Zimbabwe receives about 300 days of sunshine and an annual average of 5.7 kWh/ m²/year. The intensity of solar radiation varies with geographical location and the seasons of the year (winter and summer). It also varies with the time of the day. Fig 2 shows radiation map of Africa.

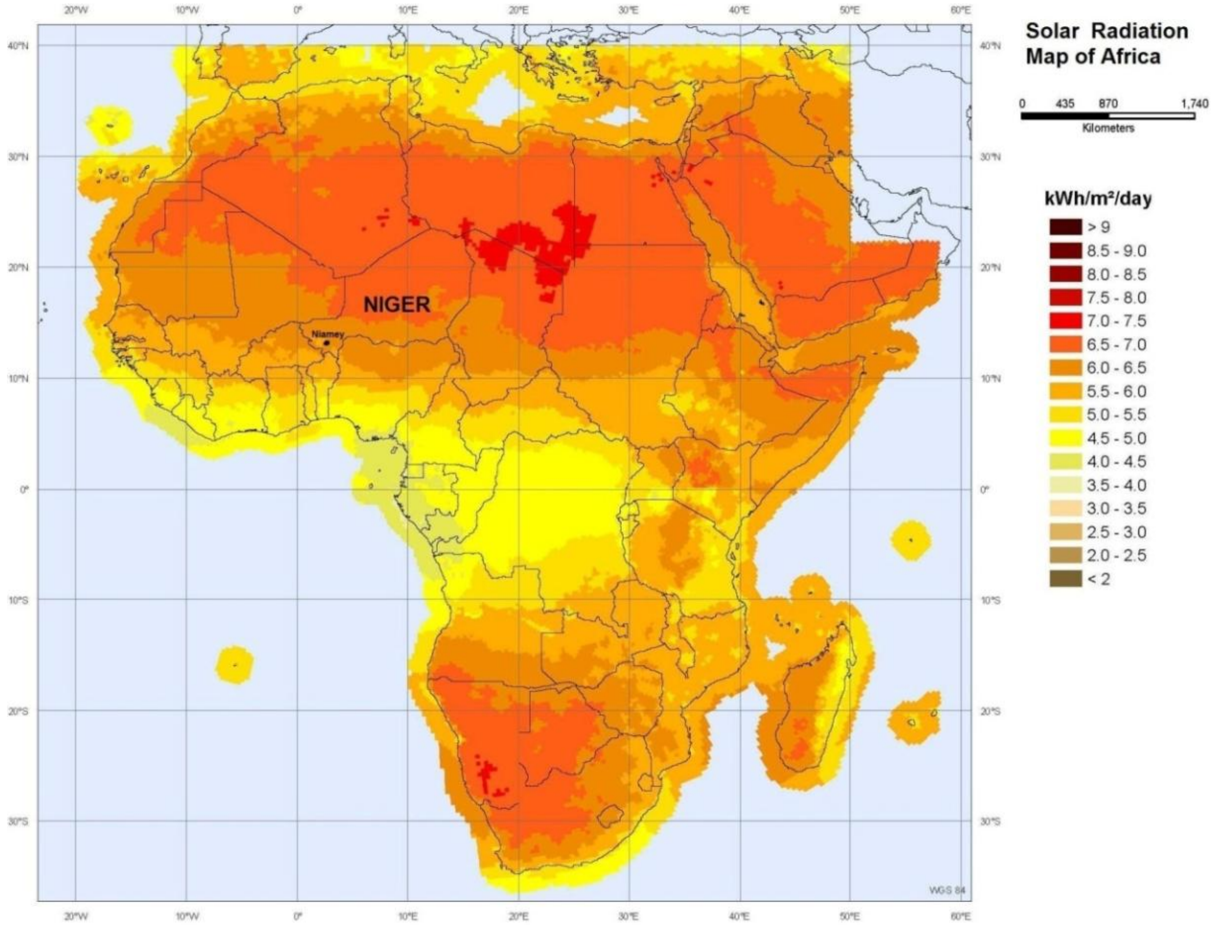

Fig 2: Radiation map of Africa (Gregoire et al., 2013)

The map shows that Zimbabwe receives an annual average radiation that range from 5,5kWh/m²/day to 6kWh/m²/day. According to Boxwell (2014), solar irradiance levels are used to calculate daily solar output levels. However irradiance levels vary at different times of the year depending on the seasons, weather and time of the day.

2.3 Solar PV applications

Solar PV energy is used in a variety of applications ranging from residential applications to productive uses such as irrigation, lighting for poultry production, livestock watering, drinking water supplies and providing power for institutions such as clinics and schools. The contribution of solar PV on residential applications have been studied extensively by researchers. Such work have been confined mostly to solar home systems as alternative solution to energy crisis in both rural and urban areas. Mhlanga and Gwamuri (2010) for example in their feasibility study, showed the potential of solar PV as an alternative source of energy for areas that are not connected to the national electricity grid in high and low density suburbs of Bulawayo. Sequel to this, International organisations such as International Renewable Energy Agency (IRENA) projections on the potential of solar PV energy have been confined to residential applications with productive uses in agriculture getting little attention. A study carried out by IRENA (2011) on the prospects for African energy sector focused on the potential of solar PV off grid power plants only for residential applications.

Despite having abundant radiation levels in Africa, these projections are silent on the potential of solar PV on productive uses to improve food security such as irrigation schemes, community drinking water and livestock watering. It is until recently that emerging work by researchers have focused on techno economic analysis (Lar et al., 2013) , environmental performance and efficiency (Maurya et al.,2015), feasibility of solar PV (Reca et al., 2015) and optimal sizing of solar PV pumping systems for irrigation as a strategy for enhancing food security in developing countries. However a comprehensive analysis on the contribution of solar PV to food security is still needed for the widespread propagation of solar PV in semi-arid areas of Zimbabwe to reduce vulnerability of rural communities to hunger through small scale irrigation schemes.

2.4 Advantages of solar PV in irrigation

2.4.1 Cost Effective

Madjoubi et al. (2010) studied the economic viability of photovoltaic water pumping in Tunisia. The study compared PV water pumping with diesel engine pumping systems using life cycle cost analysis (LCA). The study demonstrated that the LCA of diesel engine pumping is higher than the cost of solar PV pumping systems. Reca et al. (2015) analysed the feasibility of photovoltaic pumping for irrigation in the Mediterranean greenhouses. Their study also noted that solar PV for greenhouse vegetation production is a cost effective alternative as compared to conventional energy sources using breakeven analysis. Goyal (2013) found out that the replacement of diesel powered pumps by 4000 solar powered pumps in 2012 in gardens and farms in the Indian state of Rajasthan saved 2,4 million litres of fuel worth US$ 362 840. The annual savings clearly attest to economic benefits that boost the income for farmers in Indian state of Rajasthan. Qadhi (2014) also revealed that solar energy is a cost effective alternative for farmers as his study indicated the total annual fuel savings of US$ 51 million dollars in Wadi Hadhramount in Yemen. Although high upfront costs are needed for solar PV energy, the number of years needed to breakeven are two and half years and solar energy becomes cheaper in the long run. The costs of diesel based pumping become higher due to high operation costs and maintenance costs coupled with soaring diesel prices (Shinde and Wandre, 2015). In addition, solar panels have the long life span of 20 to 25 years. This make them cheaper in the long run (Madjoubi et al., 2010).

2.4.2 Low maintenance and low operation costs

One of the important advantages of solar PV is the negligible operating cost of the pump. Since there is no fuel required for the pump like diesel generators, the operating cost is minimal (Maurya et al., 2015). A well designed solar system requires little maintenance beyond cleaning of solar panels once a month or once a week. Solar pumps also require minimal attention as they are self-starting. Conventional energy sources such as diesel powered engines used mostly in off grid remote areas as an alternative require high maintenance costs. According to Maurya et al. (2015), maintenance of diesel generators include filter replacements, decarbonisation and replacements of parts such as crankshaft which require skilled personnel. Shinde and Windre (2015) further states that low maintenance and operation costs of solar PV system are due to its durability.

2.4.3 Localised/decentralised renewable energy source

According to Fakir (2013), solar energy is the most geographical localised of all power generating sources as it can be established almost anywhere in the country at the point of demand. This allows greater diversity of ownership with the socio economic benefits being felt in every location rather than in one centralised location as is the case with national electricity grid system. The decentralised nature of solar PV avoids problems such as frequent power outages and electricity rationing that negatively affect irrigation schemes.

2.4.4 Low carbon dioxide emissions

Solar energy is an environmental friendly source of energy with zero carbon foot print once installed. According to FAO (2012) integration of solar PV to food systems provides an alternative that reduces agricultural carbon footprint by eliminating the use of fossil fuel energy sources. IPCC (2007) notes that agriculture accounts for roughly 14% of global greenhouse gas emissions.

2.4.5 Adaptation to Climate Change

Adoption of solar energy fits well to the “think globally and act locally” mantra to fight global warming and adapt to impacts of climate change. Shinde and Wandre (2015) states that another important advantage of solar energy is that it is harmonious with nature. In hot and dry summer months, solar PV pumping gives maximum output of water when it is most needed. This indicates solar PV pumping for irrigation in drier parts of the world reduces vulnerability of farmers to climate change impacts such as high temperatures, rainfall variability and erratic rains. The use of solar energy however allows farmers in semi-arid parts of the world to exploit benefits from such impacts such as increased radiation levels to pump water for irrigation thereby avoiding reliance on rain-fed agriculture that is risky (Goyal, 2013). Adaptation to impacts of climate change enhances sustainable rural livelihoods and reduce food security challenges affecting small scale farmers in rural areas.

2.5 Limitations of solar PV in irrigation

According to Shinde and Wandre (2015), the initial investment cost of solar PV technology is high. At present the technology is basically surviving because of subsidy schemes availed by the government in some countries and also through support from donors and NGOs such as World Vision, SELF and Practical Action. The other downside of solar PV is that it produces variable yield. The water yield of the solar pump changes according to the sunlight. It is highest around noon and least in the early morning and evening. So it should be operated during noon time. Jayakumar (2009) adds on that solar insolation varies from location to location, so there are certain geographic limitations in generating solar power. Theft of solar panels is also another problem in some areas. So the farmers need to take necessary security measures to ensure that solar panels or other components of solar system are not stolen.

2.6 Basics of solar PV pumping system

2.6.1 Components of solar PV pumping system

According to Shinde and Wandre (2015), the components of a solar PV pumping system comprise of PV panels, solar DC water pump, pump controller and water tank. Solar panels are the main component used for driving the solar pump. Several solar panels are connected together to produce DC electricity. Interconnections are made using series or parallel to achieve the desired voltage and power the pump. Centrifugal or submersible pumps are connected directly to the solar array using DC power produced by the solar panels. Solar pumps are available in several capacities depending upon the requirement of water.

The controller plays a vital role in the system performance due to its ability to regulate the power production to match that produced by the panels with that required by the pump. It also plays a critical role in protecting the system by turning it off when the voltage is at inappropriate level, meaning too low or too high compared to the operating voltage range of the pump. This voltage protection role helps extend the lifetime of the pump and reduce maintenance requirements. . A pump controller circuity trades voltage for current, this allows the pump to start and run at reduced output in weak sunlight periods. In solar DC pumping system there is no battery that is needed to store energy, energy storage is in the form of water tank. Water is pumped to an elevated storage water tanks of varying capacities with connected water pipes to distribute water through gravity to irrigated crops.

2.6.2 Determining power output from solar panels

Solar panels are rated according to the maximum amount that they can produce under standard test conditions (STC). The maximum capacity of PV panels is called peak watt (Wp). It is also known as rated power of the panel. Jayakuma (2009) states that PV solar panels quote the expected number of watts of power they can generate, based on a solar irradiance of 1000 watts per square metre. To determine the amount of power produced by solar panels, the peak watts of a solar panel are multiplied by the average daily irradiance of an area for a certain month (Boxwel, 2014). This can be calculated as:

Solar Panel Wp x Average daily irradiance =Output in Wh/day (1)

However Jayakumar (2009) argues that efficient losses of solar panels should be considered in determining the output from solar panels. These include losses due to dust on solar panels, energy lost on energy transmission wires and energy lost on the controller. Jayakumar (2009) states that due to improvements in solar panel efficiency, inefficiencies range between 15 to 25 % depending on the solar panel technology. However most of solar panels have an efficiency of 80 -85%. Based on this efficiency, the total power output from solar panels can be calculated as:

Solar panel Wp x Average daily irradiance x 80 % (efficiency) = output in Wh/day (2)

Watt/hour is a unit of energy that is the multiplication of power in Watts and time in hours.

Solar irradiance is determined by the number of peak sunlight hours (PSH). The PSH is not the same as sunlight hours in day, it is the equivalent number of hours available in a certain location per day when the intensity is enough to produce 1Killowatt of energy (Shehadeh, 2015). Solar irradiance levels for different locations in the world have been calculated by NASA and are available for free at NASA database (Boxwell, 2014)

2.6.3 Determining energy demand for solar PV pump

According to Shehadeh (2015) there are two main methods for determining energy demand for solar PV pumping. The first method is using the pump specifications provided by the manufacture consisting of two variables which are the flow rate in cubic metres per hour (m^3/h) and the total head in metres (m). These specifications are presented in the form of pump performance charts showing pumping head and cubic metres per hour and the size of the pump in kilowatts or quoted in horse power. Fig 2.6 shows an example of a pump chart from the manufacture. The point of intersection between total dynamic head and the flow rate is the point of reference showing the water demand. It is also important to note that to pump water at a certain depth (total dynamic head) also depends on the capacity of solar pump in (kW).

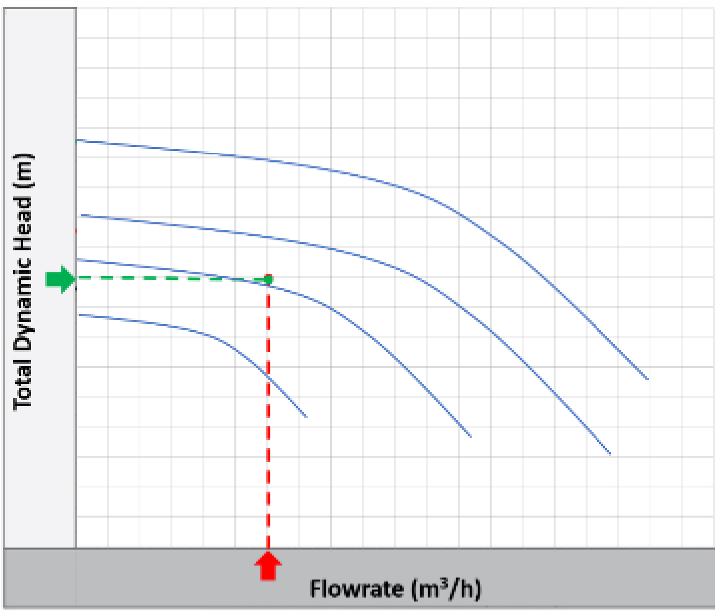

Fig 2.6 an example of solar pump chart for determining energy demand.

The second method uses a formulae that calculates pump power from the total head and the flow rate, water density and gravity. The formulae is presented as:

W = m3/h x m x kg/m3 x m/s2 x s/h   or

Hydraulic power = Flow rate x Total dynamic head x ρ x gravity/ 3600. **(3)**

Shehadea (2015) further argues that the first method of determining energy demand is the most recommended one as it refer to official datasheets published by the manufacture to avoid being too theoretical in determining energy demand and the sizing of solar panels needed to match with the demand. Solar pumps are quoted with their size either in horse power or in kilowatts.

2.7 Impacts of Solar PV powered Irrigation schemes on Food Security

Burney et al. (2009) studied the impact small scale solar powered irrigation scheme in Sudano Sahel region of Benin. The research revealed that access to water using solar PV increased both household income and nutritional intake through year round vegetable production. Income obtained augmented nutrition intake as it increased access to purchase staples and proteins during the long dry season. Their research further noted that the union of solar PV and drip irrigation increase the efficiency and reliability of solar PV pumping system. Dean (2010) adds on that solar powered drip irrigation break the seasonal rainfall dependency, which typical limits rural farmers to three to six months growing season and support the production of diversified crops in rural areas of Benin. Solar PV for irrigation also has important gender implications as it reduces the workload of women and girls in traditional water hauling.

Qadhi (2014) opines that fuel savings by using solar also increase the profits gained by farmers and carbon dioxide emissions avoided by using solar PV energy results in energy smart food systems (FAO, 2012). Foster et al. (2004) studied the reliability of solar PV water pumping in Mexico. The study indicated high degree of reliability of solar PV pumping in comparison with conventional energy sources. The reliable supply of energy is one of the important requirements for agricultural productivity. FAO (2012) asserts that solar PV improves access to modern energy services for rural communities in developing countries to produce more food without shocks such as soaring fuel prices that increase the vulnerability of small scale farmers to hunger.

Small scale farmers are globally the largest farmer group and of key importance to local and national food security in Sub-Saharan Africa (SSA). FAO (2012) report conclude that solar PV have the best prospects to improve food security and reduce poverty for small scale farmers who are the largest farmer group in SSA. The newly crafted economic blue print, the Zimbabwe Agenda for Sustainable Socio Economic Transformation (ZIMASSET) also recognises solar energy as a promising alternative for sustainable agricultural development that will boost production levels and increase resilience for small scale farmers.

In addition, access to reliable, affordable, sustainable and modern energy is a key priority area in the newly crafted United Nations sustainable development goals (SDGs) to be achieved in 2030 (Osborn et al., 2015). Integration of solar PV energy in food systems also fits well to the other two goals of United Nations SDGs which are to i) take urgent action to combat climate change and its impact and ii) End hunger, achieve food security and improved nutrition and promote sustainable agriculture (Osborne et al., 2015). Solar PV has a number of advantages over conventional energy sources which makes a viable option for pumping irrigation water.

2.8 Overview of Food Security situation in Gwanda District

Gwanda district lies in the agro-ecological region V. The region is severely affected by recurrent droughts caused by erratic rainfall and climate change. Rainfall variability, long dry spells and late onset of the rainfall season has resulted in crop failures and in a series of poor harvests. This has led to perennial chronic food insecurity which has also worsened poverty in the region. The food security situation in the district has necessitated large scale humanitarian food relief operations by a number of NGOs such as World Vison, ORAP, Oxfam and Pro Africa. The area has been relying on food aid and other project aid in the form of nutrition gardens, conservation agriculture projects and borehole drilling.

Despite these interventions, food insecurity in the district remain persistent. According to ZimVAC (2015) stunting and underweight remain high at 32.3 % and 10.1% respectively. These indicators clearly show that food shortages in Gwanda district are severe. ZimVAC (2015) reported that Gwanda district is experiencing chronic food insecurity. The report further revealed that huge current food deficits are due to widespread poor performance of the 2014/15 agricultural season.

The district experienced a delayed onset of the rainfall season which was followed by long dry spell which stretched from beginning of January to March 2015. Tshuma (2015) notes that long dry spells led to crop failures as 75% of all crops that were grown in the district in 2014/15 season were completely written off. The current high prices of maize which is the staple food were stimulated by crop failures. ZimVAC (2015) adds on that maize prices increased by 44% around February 2015 in the district and some neighbouring districts such as Beitbridge and Mangwe districts. These food security challenges are a reflection of heavy dependence on rain-fed agriculture which is risky. The food security situation in the district has been further aggravated by poor economic performance of the country.

Mhaka (2015) further reported that irrigation schemes in Gwanda south such as Rustlers Gorge and Mashaba irrigation schemes have been abandoned due to lack of funding to procure new pumps to keep them operational. According to ZimVAC (2015) 56 % of irrigation schemes established in Matabeleland South Province are non-functional while 12% are partially functional. Currently the region is in dire need of food aid. The current drought in Gwanda district and other districts in agro-ecological region V and IV has been declared a national disaster. A number of NGOs operating in the district have of late shifted from responding to drought through food handouts but through high impact interventions such as establishment of solar powered irrigation schemes. World Vision and Pro Africa have taken a leading role in partnering with communities to establish solar powered small scale irrigation schemes. These interventions are positively impacting communities to be food secure, increasing resilience and improving climate change adaptation.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 The Research Design

According to Babbie (2008), a research design is a blue print which guides the research in achieving a preferable set of objectives. It is a systematic inquiry into an event or a set of related events which aims to describe and explain the phenomenon of interest. The study employed a case study research design as it allowed the researcher to amass wide range of information on the contribution of solar PV energy on the dimensions of food security.

The researcher used this research design because of its scientific credentials which involves both qualitative and quantitative approaches. Furthermore this allowed triangulation where questionnaires, interviews, focused group discussions, actual field data and observation were used in this study. Actual quantitative photovoltaic and water data obtained from the field by the researcher was augmented by questionnaires, interviews, FGDs and direct observations at Pelele solar PV powered irrigation.

3.2 Target Population

The target population is described as the entire aggregation of respondents that meet the designated set of criteria (Babbie, 2008). The target population for questionnaires in this study constituted 30 farmers at the irrigation scheme. Due to the small population, the researcher used a sampling fraction of $^{1}/_{3}$ (one third) which translated to 10 farmers to give an in-depth insight on the role of solar PV on household food availability, dietary diversification and food stability. Focused group discussions reinforced this sample size as all 30 farmers participated during discussions sharing their experiences in using solar PV energy.

The target population also consisted of relevant institutions, irrigation management committee and community leaders that are directly involved in supporting farmers at the irrigation scheme. These included field officers from AGRITEX, NGOs, the councillor of ward 12 and village heads from Pelele village.

3.3 Sample and Sampling Procedure

Babbie (2008) referred to sampling procedure as a process of selecting units of study from a population of interest so that by studying the researcher may fairly generalize the results back to the population from which they were chosen. Stratified random sampling technique was used in this research to obtain a representative sample of the whole population. From a target population of 30 farmers the researcher used a large sampling fraction of $1/3$ which resulted in a sample size of 10. Eley et al. (2002) states that for small population less than 100, a large sampling ratio of 30% and above is needed for high degree of accuracy, in this case the sampling fraction was slightly above 30%. The total number of female and male farmers at the irrigation scheme were 18 and 12 respectively which gave a ratio of 3:2. To meet the sample size of 10, the researcher then employed simple random technique to select questionnaire respondents based on the 3:2 ratio. The researcher used stratified random sampling technique to minimise biasness. This method ensured that female and male farmers were not overrepresented or underrepresented, hence high reliability and validity of results.

The researcher also used purposive sampling on the selection of Agritex officers, irrigation management committee, councillor and village heads within the ward because they provided rich data to the researcher pertaining to their experiences with solar PV on the irrigation. Creswell (2009) pointed out that purposive sampling confines and narrows the research to specific important stakeholders who meet the required characteristics of the study subject. Purposive sampling was also used to interview organisations such as World Vision on the benefits of solar PV to communities.

3.4 Data Collection Instruments

3.4.1 Questionnaire Survey

A questionnaire is an instrument specifically designed to elicit information that will be useful for analysis. It is a document containing questions to solicit information to meet a particular need for research information about a pertinent topic (Babbie, 2008). The researcher used questionnaires (Appendix 1) to solicit data from the target population using simplified questions that gave a synopsis of the respondents' attitudes, perceptions, experiences and lessons learned with regards to solar PV. Questionnaires helped the researcher to amass information on energy accessibility, reliability, affordability and the impact of solar PV on food production and other food security dimensions. Questionnaires were designed with a combination of both closed ended and open ended questions to elicit rich qualitative and quantitative data from farmers. These questionnaires were also divided into thematic sections to ensure objectives were addressed. The researcher self-administered the 10 questionnaires to the farmers. The self-administration of the questionnaires was important in translating to the local languages (Sesotho and Ndebele) for some who did not understand English.

3.4.2. Focus Group Discussions

Focus Groups Discussion (FGDs) were used to obtain information on the sustainability of solar PV and security of energy supply. Impacts of solar PV and the challenges were noted. FGDs were also used by the researcher to understand the level of social acceptance on solar PV technology. Some questions were almost the same with those on the questionnaires, these were meant to elaborate further and to provide more insights in exploring more on the objectives of the study. Two groups of fifteen farmers each were used by the researcher to capture real life data on the topic.

3.4.3 Interviews

Semi structured interviews were used by the researcher to get information about the role of solar PV in the enhancement of food security. These key informants were important in obtaining in-depth information from organisations and individuals that are directly involved in the operation of the irrigation scheme. Notifications were made a week earlier by the researcher to seek permission on relevant stakeholders to allow them to schedule for interviews in time. Table 3 shows key informants that were interviewed and reasons for their selection.

Table 3. Respondents Interviewed and the reasons why they were chosen.

Key Informants	Reasons for selection
Agritex officer ward 12	Responsible for technical support and extension services for the irrigation including; ➢ Training ➢ Support visits
World Vision Bolamba Area Development Programme	➢ Funded the initial costs of solar PV system at Pelele irrigation scheme ➢ Provide food aid to communities in Gwanda district
ZERA	➢ Knowledgeable on current fuel prices and estimations of carbon emissions of fossil fuels ➢ Legal capacity and policy support for energy initiatives
Irrigation Management Committee(IMC)	➢ Responsible for day to day operations of the scheme with regards to operation hours of solar PV powered water pumps.They keep records on total crop yield per season. ➢ General information about the scheme.
Councillor ward 12	➢ Familiar with food security challenges in ward 12 and the prevailing socio economic and political status of the area. ➢ Knowledgeable on NGOs operating in the area under study. ➢ Coordinates with NGOs and government departments in developmental projects.
Pelele village head	➢ Familiar with the history of the study area. ➢ Knowledgeable on the socio economic status of the study area.

3.4.4 Observations

Kumar (2014) described observations as a purposeful, systematic and selective way of collecting and listening to an interaction or phenomena as it takes place. The researcher used direct observations. Observations were used to collect empirical data which included the number of solar panels, back of panel (BOP) information on wattage and voltage, and area covered by mounted solar panels. Observations were also used to obtain information regarding site attributes of solar panels, distance of the water pump from the solar panels, cleanness of solar panels and number of operation hours of the water pump. Irrigation water management techniques, crops grown and the general state of the irrigation was also observed.

3.4.5 Secondary sources of data

Desktop research was also used in this research study. Secondary data collection methods including document review were employed. Studying existing literature was imperative in critically examining the contribution of solar PV in enhancing rural livelihoods in different countries in developing and developed world. A detailed account of country experiences in using solar PV helped the researcher to come up with recommendations premised on the fact that such experiences can be replicated in Zimbabwe to close the energy gap through sustainable energy initiatives in agricultural sector. It also enlightened the researcher on current energy initiatives in Zimbabwe, current costs of solar PV systems and impediments on the widespread propagation of solar PV energy for irrigation schemes in Zimbabwe. The existing literature included journals, annual reports from organisations, institutions and individuals interested in solar PV energy. Secondary sources of data were also used to obtain data solar irradiance levels in Zimbabwe.

3.5.1 Solar PV power output calculations

Power supply from solar panels was calculated using average monthly irradiance for Gwanda extracted from NASA database. Solar panel efficiency losses were also considered in calculating daily power supply .The formulae for calculating power supply was adapted from Jayakumar (2009) and Boxwell (2014). The following formulae was used.

Solar panel Wp x Average daily irradiance x 80 % (efficiency) = Energy supply in kWh/day (1)

3.5.2 Solar pump energy demand calculations

Energy demand of the solar pump was calculated using pump specifications provided by the manufacture consisting of the flow rate in cubic metres per hour (m^3/h), the total head in metres (m), and size of the solar pump in kilowatts or horse power. This method was recommended by Shehadeh (2015). Pump specifications were obtained from pump performance chart at Pelele irrigation scheme. The formulae below was then used to determine daily energy demand.

Size of solar pump (kW) x hours of operation per day = Energy demand (kWh/day) (2)

3.5.3 Calculations of fuel savings and carbon dioxide emissions avoided by using solar PV energy at Pelele irrigation.

To calculate fuel savings and estimations of carbon dioxide emissions avoided per year, the following assumptions were made:

- A 4.5Kw diesel generator (recommended size of generator that should be three times the rated power of an electric appliance) replaces a solar array of 2.115kW to power an AC submersible pump with an equivalent flow rate of $10m^3/h$ and rated power of 1.5kW equivalent to that of solar DC pump.
- Input voltage of the AC pump is same as with solar DC pump
- Water demand is $30m^3$ per day throughout the year following an irrigation schedule on watering days.

Specifications on fuel consumption of a 4.5Kw diesel generator obtained from the market was 1.18litres/hour. Carbon dioxide emissions estimates of 2.68kg/ litre of diesel based on IPCC (2007) guidelines were used to estimate annual carbon dioxide emissions avoided by using solar PV as an alternative source of energy for irrigation. Current prices of diesel fuel per litre were used to calculate fuel cost savings.

3.6 Data Presentation and Analysis

Quantitative and qualitative types of data analysis were employed by the researcher. Raw data from interviews, questionnaires and focus group discussions was presented in tables, photographs and pie charts. This was followed by an analysis of the findings and discussion of the implications of the research results made.

The study consisted of both qualitative and quantitative data which was presented and analysed differently. Quantitative data extracted from questionnaires was analysed using Microsoft excel to establish the relationships between set of variables such as solar irradiance levels and power output from solar panels. Microsoft excel was also used in the production of graphs showing relationships between solar irradiance and solar output and energy demand.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents and analyses results obtained from questionnaires, field observations, secondary sources of data and interviews on the role of solar PV energy in enhancing food security.

4.1 Socio demographic information of respondents

The results showing the socio-demographic characteristics of respondents which comprise of gender, age, education attainment and household size were obtained from the 10 respondents that were sampled out of a target population of 30 using stratified random sampling. From the questionnaires the study revealed that 60% of the respondents were females and 40% were males. Sex distribution of respondents was important because it shows how access to solar PV energy impact the roles of men and women in household food security. High percentage of female respondents revealed that women play a major role in enhancing food security. Figure 4.1 shows the sex distribution of the respondents.

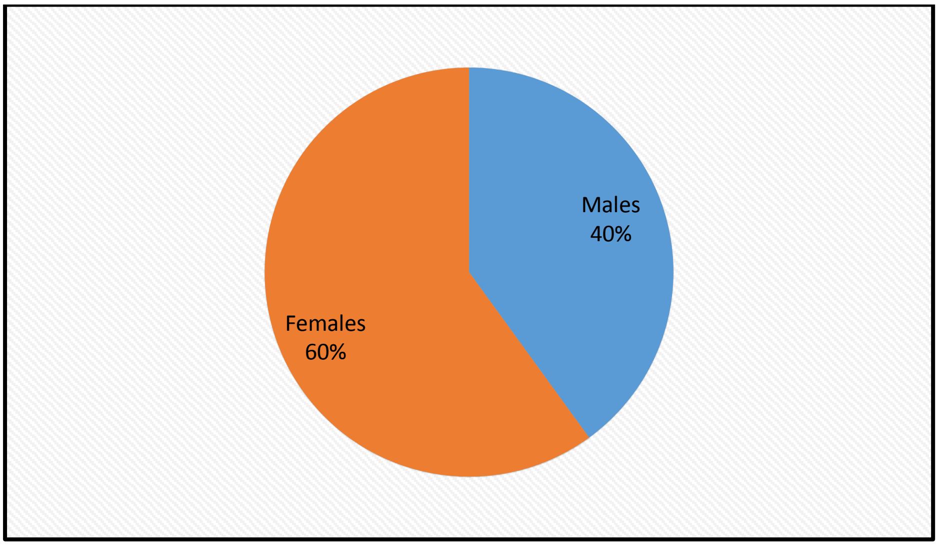

Figure 4.1 Sex of respondents

The Findings from the administered questionnaires showed that the most dominant age group was 28-39 years category which constituted 50% followed by 40-50 years with 30%, 18-28 years and 51+ with 10% as shown in fig 4.2.

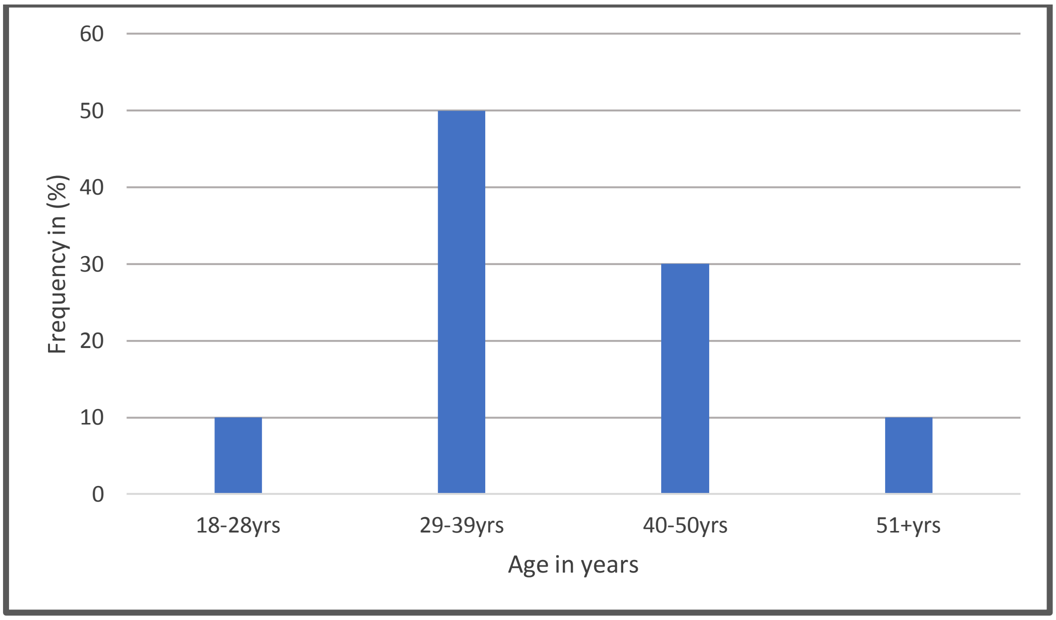

Fig 4.2 Age distribution of respondents.

Education attainment of respondents was also an important socio demographic characteristic to consider as it determines the levels understanding, perceptions and attitudes on using solar PV energy. Fig 4.3 show the results of education attainment of respondents.

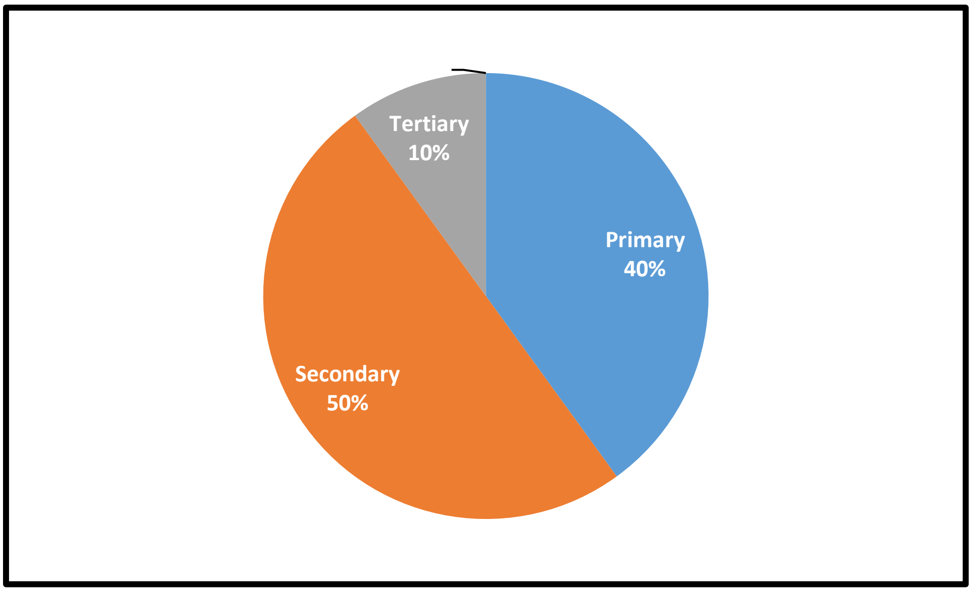

Fig 4.3 Educational levels of respondents

Fig 4.3 reflect that 50% of the respondents attained secondary education, whilst 40% and 10% attained primary and tertiary education (university/college)respectively. The highest proportion of 50% representing secondary education obtained by respondents has a positive impact on perceptions, knowledge and attitudes of individuals on solar PV energy.

Another important socio demographic characteristic was the household size which is one of the important determinants of household food security which affect food availability, access, stability and utilisation. The bigger the household size, the shorter the duration of food stocks and reduced nutritional intake. The average household size noted from the questionnaire was 6, slightly above the national average of 4.4 ZIMSTATS (2013). Results from the questionnaires revealed that the main sources of livelihood of the respondents were farming and livestock production. None of the respondents were employed. Questionnaires further revealed that the size of plot for each farmer was 330 square metres. It was further noted from questionnaires that all respondents joined the irrigation scheme in 2010 when it was established.

4.2 Impacts of solar PV on food security

Results from questionnaires revealed the beneficiary impacts of solar PV energy on food security. The impacts identified were tabulated in table 4.2.

Table 4.2 Impacts of solar PV on food security indicated by questionnaire respondents.

Beneficiary impacts of solar PV on food security	Frequency in (%)
Increased food production/ higher crop yields	70
Increased household income	30
Improved food stability	60
Cost savings	50
Multiple crops grown per year	40
Improved nutritional intake	30

Research data 2015

Table 4.2 shows that the highly mentioned impacts were increased food production which recorded 70% of response followed by improved food stability and cost savings with 60% and 50% respectively. Improvements in household income and nutritional intake were less mentioned by respondents.

4.2.1 Increased food production

Food production is an important indicator of food security as it measure the extent of food availability and stability of supply. Table 4.2 shows that increased food production was the mostly mentioned impact of solar PV energy. Responses from FGDs concurred with questionnaire responses as they indicated that the availability of free energy from the sun throughout the year boosts food production as crop production is done all year round.

Questionnaire respondents and FGDs further attributed increased production to expansion of irrigation area after the installation of solar PV system. Results on irrigation size and types of crops grown before and after the installation of solar PV were tabulated in table 4.2.1.

Table 4.2.1 Irrigation size and crops grown before and after installation of solar PV system

	Before installation of solar PV (manual pumping)	After installation of solar PV pumping system in 2012
Irrigation size (ha)	0.5ha	I ha
Types of crops grown per year	Green vegetables	Green vegetables Butternuts Groundnuts Maize Wheat Tomatoes Sugar beans
Number of farmers	30	30

Source: Research data 2015

Table 4.2.1 shows that the irrigation size before installation of solar PV was 0.5ha and after the installation of solar PV system irrigation area expanded to 1ha. Table 4.2.1 also indicate that before installation of solar PV food production was limited to green vegetables only and multiple crops were grown after the adoption of solar PV pumping. It was also noted from key informant interviews and FGDs that high flow rates and high discharge capacity of solar PV pumping necessitated the expansion of irrigation area in 2012 when the solar PV system was installed. Interviews with IMC further revealed that before the installation of solar PV system at Pelele irrigation scheme, crop production was limited to vegetable production only due to low discharge capacity of manual water pumping and frequent borehole breakdown. FGDs also added that manual pumping was too labour intensive and time consuming, therefore crop production was done only in winter as irrigation activities competed with rain-fed agriculture in November to April during the growing season.

Production yields of different crops for the years 2013 and 2014 after the installation of solar PV system obtained from interviews with the IMC quantified and supported the benefits mentioned by questionnaire respondents indicated in table 4.2. Production yields for the year 2013 and 2014 were tabulated in table 4.2.2

Table 4.2.2 Total yield of crops produced at Pelele irrigation

Crop	Total yield in tones/per crop in 2013	Total yield in tones/crop in 2014
Maize	12.7	13.5
Green vegetables	10	10.1
Tomatoes	2.8	2.6
Wheat	2.6	2.7
Butternuts	9.6	9.9
Sugar beans	-	1.3

Source: Research data 2015

Table 4.2.2 quantifies the benefits of solar PV energy on food production as it show an increasing trend of crop yields from 2013 to 2014 except for tomatoes which declined in 2014. The possible reason for the yield decline of tomatoes could be the post-harvest losses due to lack of refrigeration at the irrigation scheme. Table 4.2.2 show that the yield of maize was high which recorded 13.5 tons in 2014, followed by green vegetables and butternuts which recorded 10.1 and 9.9 tons respectively in 2014.

Despite low production outputs of wheat and sugar beans, a slight increase in production output of these crops was recorded in 2014. High output of maize could be attributed to the fact that it is the staple food of Zimbabwe. Thus high yields allows farmers to stretch their food stocks for long periods to eliminate recurrent drought and seasonal shortages of food that are experienced in Gwanda district. Although there are many agricultural inputs that may be attributed to increased production of crops at Pelele irrigation, it must be noted that the energy source for irrigation water pumping is the key driver for sustained food production. The source of energy determines water availability, consistency, sufficiency and reliability to maintain a smooth flow of irrigation activities. FGDs pointed out that solar PV pumping enhances water sufficiency and consistency of supply through drip irrigation, hence allowing for sufficient quantities food to be produced on a consistent basis.

4.2.3 Multiple crops grown in a year

Results for average crop yields per farmer for the 2014 season obtained from questionnaire respondents were presented in table 4.2.3

Table 4.2.3: Multiple crops grown in a year at Pelele irrigation and average yield per farmer in 2014.

Name of crop	Average yield per farmer in Kilograms(kgs)/season
Maize	510.2
Butternut	340
Groundnuts	150
Wheat	90
Green vegetables	450
Tomatoes	60
Sugar beans	40

Source: Research Data 2015

Multiple cropping shown in table 4.2.3 indicate that solar PV pumping allows for continuous crop production (year round cropping) that eliminates dependency on short rainfall season that is only limited to three to five months. Interviews with Agritex officer revealed that before the installation of solar PV system, crop production at Pelele irrigation was limited to vegetables only due to low flow rates, low discharge capacity of manual pumping and frequent borehole breakdown. The Agritex officer further revealed that good radiation levels throughout the year allows for year round pumping to meet crop water requirements throughout the year. The reasons for growing these multiple crops obtained from questionnaire respondents were to increase crop production, improve nutrition intake and augment income. This clearly shows that growing multiple crops in a year at Pelele complements other benefits of solar PV pumping.

4.2.2 Food stability

The researcher noted that solar PV energy enhances sustained food production at Pelele Irrigation scheme. Fig 4.2 shows that food stability was highly mentioned by questionnaire respondents as a beneficiary impact of solar PV pumping for irrigation. Interviews with the Agritex officer pointed out that the infinite source of energy for solar PV offsets fluctuations in food production that are caused by shocks such as rising costs of conventional energy sources and maintain stability of food production. Interviews with the councillor added on that solar PV pumping allows farmers to obtain food overtime through irrigation, promoting food stability thereby eliminating chronic and transitory food insecurity. Sustained food production levels at Pelele irrigation scheme indicated in table 4.2.2 can offset the effect of economic shocks such as rising food prices on household food security in Gwanda. Farmers at Pelele solar powered irrigation scheme may cope with these economic shocks through social safety nets such as barter trade. Barter trading could boost food access through exchange of food produced from the irrigation scheme with other basic needs needed to improve household food security.

4.2.3 Cost savings

Table 4.2 shows that 50% of questionnaire respondents indicated that solar PV energy enhances cost savings. The high percentage is an indication that solar PV play a pivotal role by significantly lowering operation and production costs while increasing food production at Pelele irrigation scheme. It was noted from questionnaires and FGDs that World Vision, an international NGO funded the initial establishment of solar PV system at Pelele irrigation scheme in 2012.

Cost savings were also calculated assuming a decentralised energy source such as diesel generator replaces solar PV system at Pelele irrigation scheme.Assuming a 4.5kw diesel generator (recommended size of generator that should be three times the rated power of an electric appliance) to power an AC submersible pump to meet daily water requirements. Using generator specifications obtained from the market on fuel consumption per litre was 1.18litres/ hour, the researcher found out that 910litres of diesel fuel are saved annually by farmers at Pelele solar powered irrigation. Using the current diesel fuel prices in Zimbabwe obtained from ZERA, the annual fuel cost savings would be US $1092. High crop yields at Pelele irrigation can be attributed to significant operation costs avoided by using solar PV energy as costs avoided could be invested in other agricultural inputs. With the increasing maize grain prices restraining food access in Gwanda district, high crop yields and crop diversity at Pelele irrigation scheme can enhance farmers to be self-sufficient, therefore eliminating high food prices experienced in the district as reported by ZimVAC (2015). Calculated costs savings were also augmented by advantages of solar PV noted from administered questionnaires and FGDs were free energy source, high reliability and minimal operation and maintenance costs.

4.2.4 Increased income

Results presented in table 4.2 show that only 30% of questionnaire respondents mentioned that solar PV energy boosts household income, this could be due to the fact that some farmers do not sell much of their produce so as to cater for large family sizes. It was noted from FGDs that income was obtained from selling surplus vegetables, butternuts and tomatoes. The researcher averaged the income obtained from questionnaire respondents. The average income obtained by respondents was $210. It was also noted from discussions that crop diversification at Pelele irrigation increased household income and the income obtained was used to purchase non-food staples and supplement maize supplies(staple food) when shortages arise during the year.

4.2.5 Improved nutritional intake

Table 4.2 show that 30% of questionnaire respondents indicated solar PV energy improves nutritional intake. Discussions with farmers revealed that various crops grown at Pelele irrigation increased consumption of food of high nutrient value and enhanced dietary diversity. It was also encouraging to note from FGDs that income generated from the sale of vegetables and butternuts was used to purchase high nutrient value food. In addition, it was also learnt from FGDs that surplus green vegetables are dried and reserved for the time of the year when the cycle of vegetation has ceased. Dried vegetables (*umfushwa)* provide a valuable source of protein. The findings of the study are consistent with the findings of Burney et al. (2010) who found out that solar powered drip irrigation augments household nutritional intake in semi-arid areas.

4.2.6 Low carbon footprint

Interviews with ZERA revealed that one of the greatest environmental benefits of solar PV in food security is that it reduce carbon footprint of agrifood food systems. Solar PV energy therefore enhances a win-win scenario, thus ensuring socio-economic gains at the same time reducing carbon dioxide emissions. Estimates of carbon dioxide emissions avoided by using solar PV energy for irrigation was calculated by the researcher using IPCC (2007) guidelines for diesel which was 2.68kg/litre and the estimates of diesel fuel saved annually which was 910 litres. The estimates of carbon dioxide emissions avoided by using solar PV calculated by the researcher were 2438.8kg. The significant amount of carbon dioxide emissions avoided reflect that solar PV enhances food security for small scale farmers at Pelele irrigation while reducing the carbon foot print.

4.2.7 Time savings

Distance travelled by farmers to Pelele irrigation scheme obtained from questionnaire respondents was averaged and compared with average distance to irrigation schemes that are connected to the electricity grid system. This was done to determine the extent of physical access to the energy source. The results were presented in Fig 4.2.7.

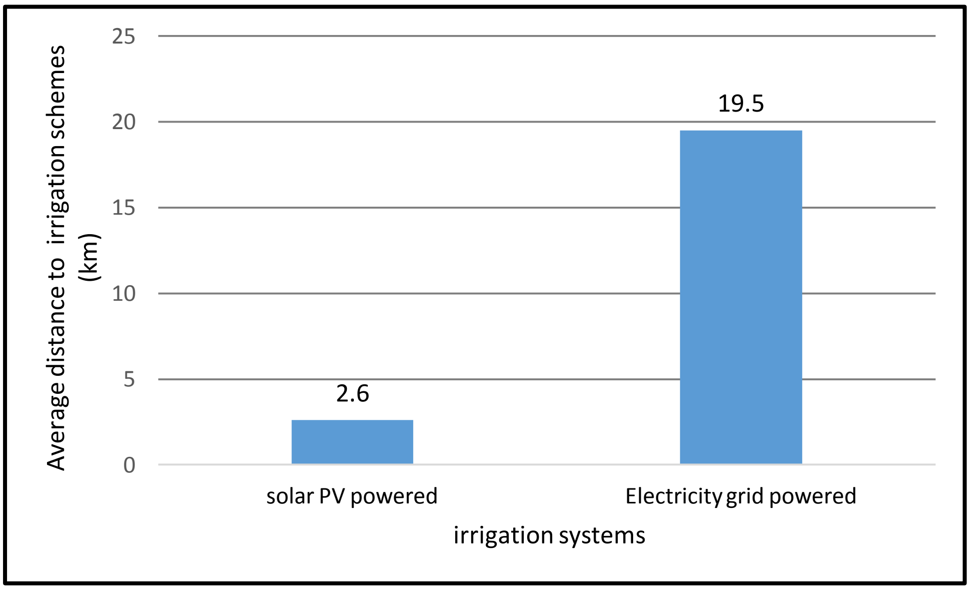

Fig 4.2.7 Average distance travelled to irrigation schemes

Fig 4.2.7 shows that the average distance travelled by farmers to Pelele solar powered irrigation was 2.6km whilst average distance travelled to electricity grid powered irrigation schemes was 19.5 kilometres. Distance travelled by farmers is of great importance because it affects time spent on travelling to the irrigation which in turn affects agricultural production. Longer distances lead to delays in carrying out irrigation activities such as watering and weeding. The localised nature of solar PV energy enhances physical accessibility as shown in fig 4.2.7. Physical accessibility to the irrigation improves food availability and physical accessibility of food. It was also noted from the FGDs that solar PV eliminates time taken in manual pumping of water. Time savings can be invested in other activities that improve household food security. The study findings corroborates with the findings of Kumar (2013) who propounded that farmers using conventional energy sources for irrigation such as electricity grid and manual pumping pay more in terms of time. Examples of irrigation schemes that are powered by a centralised electricity grid system were noted during FGDs. These were Makwe and Guyu- Chelesa irrigation schemes where beneficiaries travel more than 15 kilometres using scotch carts and bicycles to these irrigation schemes.

4.2.8 Other Benefits

Results of sex distribution presented in fig 4.1 revealed that females were the dominant group at the irrigation scheme (60% of respondents). The introduction of solar PV energy has important gender implications as women are relieved from the burden of spending much of their time in manual pumping of water. Time savings by women at Pelele irrigation can be invested on other social safety net activities to fight hunger and improve household food security.

4.3 The reliability of solar PV energy as an alternative source of energy for irrigation

The reliable supply of power is one of the most important requirements for agricultural production. The consistency and availability are important indicators of energy reliability. Results from the administered questionnaires revealed respondents perceptions on the reliability of solar PV based on their experiences. Respondents were asked to rate solar PV energy based on excellent, good, adequate and poor ratings. Respondent's perceptions showed a high degree of reliability of solar PV. 80% of respondents rated solar PV as excellent, 10% of respondents rated solar PV as good while 10% rated it as adequate. None of the respondents rated solar PV as poor. Fig 4.3 shows these ratings by respondents.

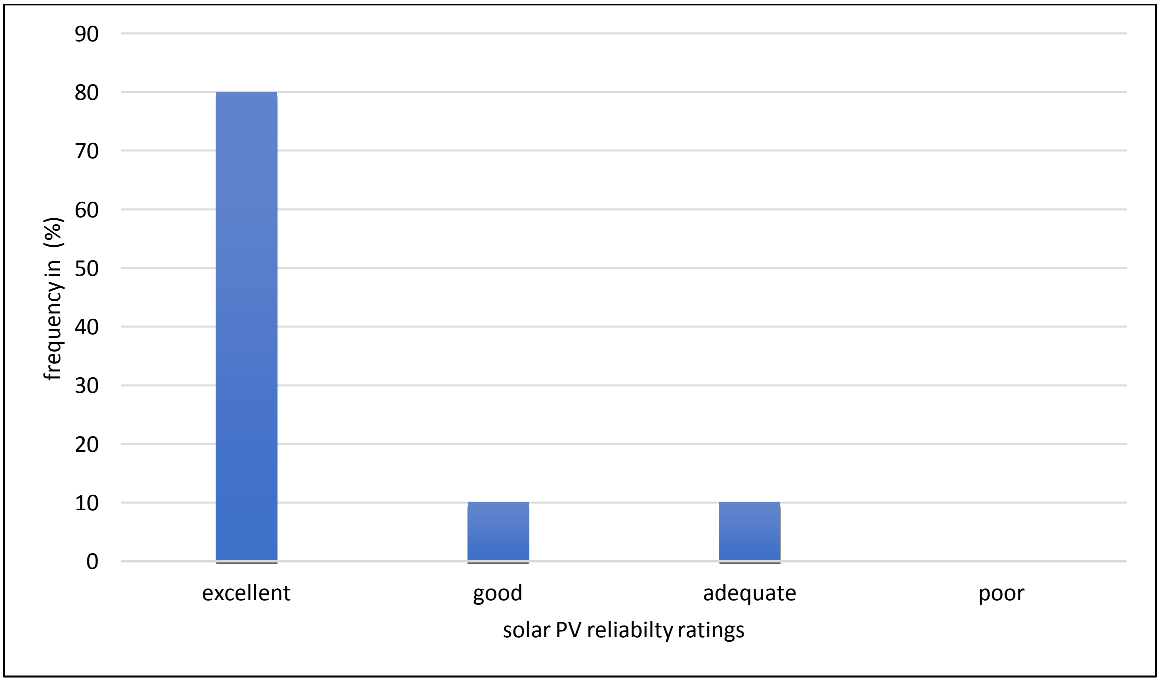

Fig 4.3 Respondent's perceptions on the reliability of solar PV energy.

Determining the reliability based on respondent's perceptions was very important because it shows the degree of satisfaction, in this case farmer's satisfaction reflected a high degree of reliability. Interviews with Agritex officer pointed out that high reliability of solar PV is due to good radiation levels throughout the year at Pelele that enhance consistency of power supply and interruptions are only experienced on cloudy days. Radiation levels for Gwanda were extracted from NASA database to determine the reliability based on monthly radiation averages to calculate power supply. Table 4.3 shows monthly averaged radiation incident on an equator pointed tilted surface.

Table 4.3 Monthly averaged radiation for Gwanda in Zimbabwe

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Annual average**
Monthly averaged radiation ($kWh/m^2/day$	6.46	6.18	5.77	5.44	5	4.38	4.77	5.57	6.32	6.30	6.27	6.28	**5.72**

Source: NASA (2015)

The study was carried out in September which is the second highest month with peak radiation levels as shown in Table 4.3. Average daily power output from solar panels was calculated based on the monthly radiation averages to determine whether power supply meets the daily energy demand. Efficient losses of 20% were considered in calculating power supply. The formulae of calculating power supply was adapted from Jayakumar (2009) and Boxwell (2014). The formulae used was:

Solar panel Wp x Average daily irradiance x 80 % (efficiency) = Energy supply in kW/h/day,

Thus, 2.115kW x 6.32kWh/day x 80% = 10.69kWh/day (for the month of September)

The results for average daily power output was presented in fig 4.4.

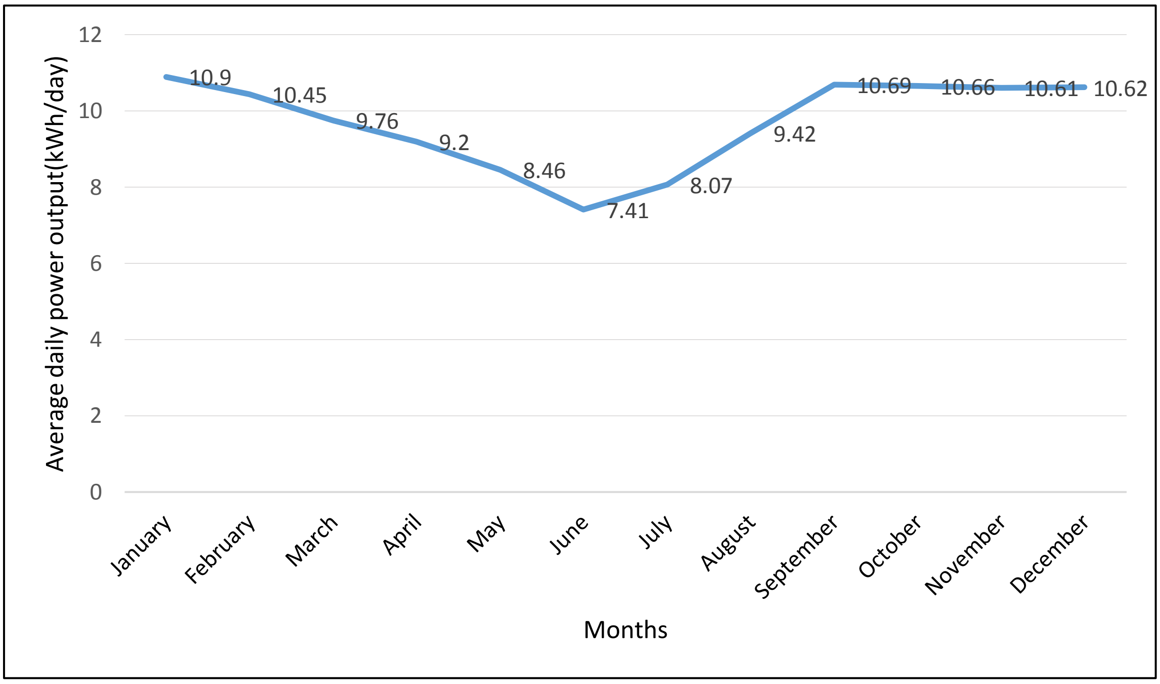

Fig 4.4 Average daily power output per month from an array of 2.115kW.

Fig 4.4 shows that January has high average daily output with 10.9kW/h/day followed by September with 10.69kW/h/day. June has the lowest average power supply of 7.41kW/h/day. Observations by the researcher found out that energy demand for September was 4.5kWh/day. Findings from observations were further supported by interviews with irrigation committee who pointed out that operation hours for the pump to meet water demand of 30m^3 per day was 3 hours throughout the year except when the sky was fully overcast. This revealed that energy demand per day was 4.5kWh throughout the year. Energy demand was calculated using a formulae adapted from Shehadeh (2015). The formulae used was:

Rated power/size of solar pump (kW) x hours of operation per day= Energy demand (kWh/day)

Interviews with the irrigation committee showed that daily watering of plots followed a schedule as 30 farmers are divided into five groups. Each group comprises of 6 farmers who water their plots once a week (Monday to Friday).

The study furnishes overwhelming results as power supply exceeds energy demand of 4.5kWh/day in peak months and in winter months (May, June, and July) with low solar irradiance levels. In September, daily average power supply exceeds daily energy demand by 6.19kWh. In June, the average daily power output exceeds daily energy demand by 2.91kWh. Based on these results, the study shows great reliability of solar PV energy at Pelele irrigation scheme shown by availability and consistency of power supply that meets energy demand throughout the year.

However, the study noted that the solar PV system at Pelele irrigation scheme is too much oversized as much of the energy supplied is underutilized and considered loss, care must therefore be taken in sizing of solar PV system. System sizing using solar irradiance levels enables accuracy and optimum sizing.

Participants during FGDs further revealed that apart from the stable power supply from solar panels, the performance of solar PV pump was highly reliable owing to its durability. This was indicated by participants during FGDs when asked to recall the last time they repaired the solar pump. Participants revealed that since the pump was installed in 2012 it has never had any breakdown. With uncertainties over unpredictability of power supply being removed coupled with high reliability, performance and efficiency of solar pump, farmers at Pelele irrigation scheme can confidently plan ahead and improve crop yields with no power disruptions. Plate 4.3 shows solar panels at Pelele irrigation scheme.

Plate 4.3 Solar panels facing North at Pelele irrigation scheme. (Source: Research data, 2015)

4.4 Solar PV potential in enhancing food security

The ample availability of energy source for solar PV shows a great potential of this energy in enhancing food security in Gwanda District. Desktop research revealed that Gwanda lies in region of Zimbabwe which receives average annual irradiation of 2100kWh/m² (SolarGIS, 2014). Interviews with World Vision Bolamba ADP manager revealed that high irradiation levels reflects a huge potential of solar PV to power community gardens, irrigation schemes and other productive applications to improve food production and reduce the plight of food insecurity.

4.4.1 Potential productive uses of solar PV in food security.

Questionnaire respondents revealed a number of food security activities that can be stimulated by the introduction of solar PV energy. These were presented in fig 4.4.1

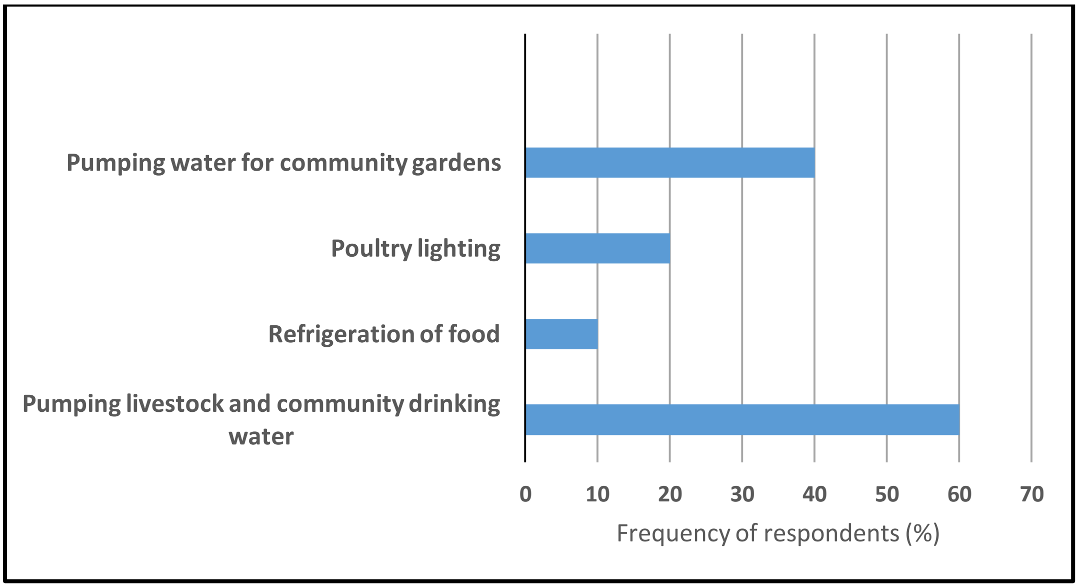

Fig 4.5 Potential productive uses of solar PV in food security: Research data 2015

Fig 4.5 indicate that pumping community drinking water and water for livestock was a highly mentioned potential followed by pumping water for community gardens. Less mentioned were poultry lighting and refrigeration. Due to erratic rains in Gwanda district, the plight of water scarcity severely affects communities. Compounding this challenge is the frequent borehole breakdown coupled with high costs of repairs and maintenance which in turn affect steady supply of potable water communities and water for livestock. Solar PV therefore presents a huge potential as highlighted in fig 4.5 for low cost water pumping of potable water and water for livestock by replacing obsolete borehole pumps in malfunctioning boreholes and abandoned boreholes.

The main source of livelihood indicated by questionnaire respondents were farming and livestock production. It is therefore important to note that solar PV pumping for livestock may have important implications on food security as more animals such as small livestock (goats, sheep) can be raised. Interviews with Agritex officer revealed that water scarcity is severe in hot dry summer months (August, September, October and November) affecting mostly domesticated animals due to drying up of dams. Results on solar irradiance data shown in table 4.3 reflect a huge potential to pump water for livestock during these summer months which have high solar irradiance levels with mean values of 6.12kWh/day above annual average of 5.7kWh/day/year.

FGDs pointed out that areas in ward 12 differ in their yielding capacity of groundwater, however it was noted that there is a huge potential for irrigating drought tolerant crops such as millet and sorghum especially in upstream villages such as Makokwe village. Interviews with ZERA revealed that the current prices of solar PV are high beyond the reach of small scale farmers to adopt solar PV energy for productive uses to enhance food security. It was noted from ZERA that the average price of solar panels is US $1.11, this means that a 235W solar panel costs US $260.

4.4.2 Energy sharing

The total annual power produced by an array of 2.115kW calculated using the annual solar irradiance average of 5.7kWh/m²/year and also considering efficiency losses was 3520kw/h/year. The total annual energy demand using peak energy demand was 1170kWh/year. A total of 2350kWh/year energy shows excess energy that is not used and is considered loss. Excess power produced by solar panels at Pelele irrigation scheme presented a huge potential for applications such as solar powered refrigerators for refrigeration of perishables such as tomatoes to reduce post-harvest food losses at the irrigation scheme. FGDs pointed out that the potential is huge for applications such as solar powered grinding meal to utilise energy that is underutilised at the irrigation scheme. It was also noted from FGDs that the underutilised energy at Pelele irrigation can also be utilised on low energy load applications such as poultry lighting at the irrigation scheme through energy sharing. However such energy sharing potential will require a lot of training on photovoltaic energy and energy storage batteries that will require high initial capital costs.

4.4.3 Current national and international initiatives that support the adoption of solar PV energy in Zimbabwe.

Desktop research revealed that there is no clear policy on promoting uptake of solar PV for irrigation in Zimbabwe. It was further revealed that the energy regulatory body, ZERA does not have a mechanism for reducing prices of solar PV systems. Limited technical information on solar PV energy still persist. However, desktop research further revealed a number of national and international initiatives that are a great pointer towards promoting high uptake of solar PV as a panacea to food security challenges. The Zimbabwe economic blue print, ZIMASSET is a compelling example of the national plan to improve food security by incorporating solar PV into the national energy mix (ZIMASSET, 2013). The researcher noted that the plan create an enabling environment for a multi-sectoral approach in addressing food security issues in Zimbabwe as it seeks coordination of agricultural and energy policies. In the economic blue print, solar PV is cited as the promising energy to power irrigation schemes and community gardens in remote off-grid rural areas of Zimbabwe.

Document review further revealed that Zimbabwe is signatory to the newly crafted United Nations sustainable development goals (SDGs) to be achieved by 2030 (Osborn et al., 2015). It was noted by the researcher that the potential of solar PV to enhance food security is huge as it is embedded on two key priority areas of SDGs which are to ensure access to affordable, reliable, sustainable and modern energy for all. The second priority area in which Zimbabwe is committed to achieve by 2030 is to end hunger, achieve food security, improve nutrition and promote sustainable agriculture.

It is clear that these goals are going to shape policies and strategies for enhancing food security in Zimbabwe, hence the great potential of solar PV energy as one of renewables to enhance food security. The researcher safely believes that these plans will foster private-public partnerships and key investments in Solar PV energy in Zimbabwe. This can result in falling prices of solar PV systems and increase in the uptake of this technology in rural areas of Zimbabwe such as in Gwanda district to end food security challenges through irrigation development and other productive uses of solar PV.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS.

5.1 Conclusion

In conclusion, the researcher found out that solar PV energy significantly enhance food security in arid southern parts of Zimbabwe. Abundant radiation levels in ward 12 enhances a stable supply of power for irrigation water pumping. Availability and consistent power supply at Pelele irrigation has greatly enhanced food availability, food stability, food access to irrigation farmers. Ward 12 is currently experiencing chronic food insecurity due to drought caused by erratic rains and extended periods of dry spells. The researcher found out that access to solar PV energy for irrigation has increased food production and reduced vulnerability of farmers to natural shocks such as drought caused by long dry spells and erratic rainfall. The researcher also found out that different crops grown at the scheme such as maize, groundnuts and vegetables eliminate chronic food insecurity that is experienced in ward 12. Solar PV energy at Pelele irrigation has enabled year round crop production and crop diversification. This has greatly increased consumption of high nutrient value crops and has augmented household income which is used to supplement household food supplies. Moreso the researcher also found that the decentralised nature of solar PV energy has improved physical access to food as power supply for irrigation is produced locally.

Erratic rains, long periods of dry spells and recurrent droughts are forecast to persist in arid areas of Zimbabwe due to climate change. The researcher found out that solar PV powered irrigation schemes improve adaptive capacity and enables communities to cope with effects of climate change.

5.2 Recommendations

- ❖ The Ministry of Energy through the department of Rural Electrification Agency (REA) should partner with the Ministry of Agriculture, Mechanisation and Irrigation development to train farmers in rural areas on solar PV applications in Irrigation schemes. These ministries should embark on training programs that address current knowledge gap regarding the food, energy and water relationships to increase the uptake of solar PV energy that is combined with drip irrigation system and precision irrigation.
- ❖ A multi-sectoral approach is needed between the Ministry of Environment, Water and Climate, Ministry of Energy and the Ministry of Agriculture, Mechanisation and

Irrigation development to improve access to information on the benefits of solar energy in food security and promote irrigation of drought tolerant crops in arid areas of Zimbabwe.

- The government should subsidise the prices of solar energy systems including solar pumps and solar panels to increase uptake of this technology for irrigation water pumping in semi- arid areas of Zimbabwe.
- NGOs assisting communities with solar powered irrigation systems such as World Vision and Pro Africa should seek technical expertise on sizing of solar PV system to avoid oversizing or under sizing. Oversizing of the solar PV system gives a wrong impression that solar powered irrigation systems are too expensive.
- NGOs and the department of Irrigation should facilitate exchange visits to promote knowledge and technology transfer among communities on solar powered irrigation systems.
- The ministry of Agriculture, Mechanisation and Irrigation development should partner with NGOs to replace diesel engine pumps with solar PV system on abandoned irrigation schemes in Gwanda district.

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APPENDIX 1: Questionnaire for plot holders at pelele irrigation scheme.

My name is Tellmore Ndlovu. I'm a fourth year student at the Midlands State University doing BSc Honours degree in Geography and Environmental Studies. I am conducting a study on the role of solar PV in enhancing food security focusing on Pelele solar powered irrigation. The responses you give are for academic purposes and confidentiality is guaranteed.

QUESTIONAIRE NUMBER…………………………………

SECTION A: SOCIO-DEMOGRAPHIC DATA

1. Gender: Male ☐ Female ☐

2. Age: Under 18 ☐ 18-28 ☐ 29-39 ☐ 40-50 ☐ 51+ ☐

3. Education: Primary level ☐ Secondary ☐ Tertiary ☐

4. Marital Status: Married ☐ Single ☐

6. Household size……………………………

7. Occupation………………………………..

8. Source(s) if livelihood……………………………………………

9. When did you join the irrigation scheme………………..

10. What is the total size of your plot………………

SECTION B: IMPACTS OF SOLAR PV ON FOOD SECURITY

11. What are the beneficiary impacts of using solar PV for irrigation? Please list below.

12. What methods were you using to pump water before this system was installed?....................

……………………………………………………………………………………………..

13. What were the disadvantages of those alternatives you used? …………………………….

……………………………………………………………………………………………
…………………………………………………………………………………………….

14. How did those energy sources affect your production yields and food stability?...
....

15. What were crops grown before the installation of solar PV………………………………..

…………………………………………………………………………………………….

…………………………………………………………………………………………….

16. What are the advantages of solar PV compared to alternatives you used before?...
....
....

17. What are the types of crops grown in your plot? Please give details of crops grown and yields per crop for the last season (2014 season)

Field crops grown at your plot	Yield per crop in Kilograms(kg)

18. Why did you choose to grow these crops? …………………………………

……………………………………………………………………………………

………………………………………………………………………………………

19. How long does the food produced sustain you and your family?..............................

…………………………………………………………………………………

20. Do you sell some crops that you produce in your plot? Yes ☐ No ☐

21. If yes, give an estimate of the income you get from selling from these crops…………….

22. What are the constraints of using solar PV?...

…………………………………………………………………………………………

23. How long is the distance from your home to the irrigation scheme?…………….

SECTION B: RELIABILITY OF SOLAR PV AS AN ENERGY SOURCE FOR PUMPING IRRIGATION WATER

24. When was the solar PV system installed for pumping irrigation water?............................

25. How do you rate reliability of solar PV as an alternative source of energy for irrigation?

Excellent ☐ Good ☐ Adequate ☐ Poor ☐

26. When was the last time you repaired solar PV system?…………..

27. What are the technical challenges that you have encountered in using this technology?……………………………………………………………………………….

……………………………………………………………………………………………..

28. Does the energy supply match with water demand to allow you sustain your crop yields in each cropping season?...

………………………………………………………………………………………………

SECTION C: SOLAR PV ENERGY POTENTIAL IN ENHANCING FOOD SECURITY.

29. What are the lessons learned in using solar PV system for irrigation?.............................

…………………………………………………………………………………………….

…………………………………………………………………………………………….

30. In your opinion, apart from water pumping what other applications can be stimulated by solar PV energy to enhance food security?...

……………………………………………………………………………………………..

……………………………………………………………………………………………..

31. Can this technology be transferred to other villages in ward 12?.....................................

……………………………………………………………………………………………..

APPENDIX 2: Focus Group Discussion Guide

1) When did you start to use solar PV energy for pumping irrigation water?
2) What methods were you using before solar PV system was installed?
3) What challenges were you facing in using those alternative sources of energy?
4) Who funded the initial establishment of solar PV system?
5) What are the reasons for growing the crops grown at the scheme?
6) Do you see production levels rising under the current energy supply?
7) What are the advantages and disadvantages of using solar PV for irrigation?
8) What are the energy supply constraints that you are facing with using solar PV systems?
9) What do you think could be possible solutions to counter those constraints?
10) When was the last time you repaired the solar pump?
11) How often do you water your plots?
12) What are the lessons learned from using solar PV energy technology?
13) Can this technology be transferred elsewhere in ward 12 or in the whole district?
14) With erratic rainfall and high temperature levels and ground water level falling, do you think the current crops grown are sustainable and will not deplete underground water?
15) What are water conservation techniques used at the irrigation?
16) For areas with low amount of ground water, can this technology be replicated to pump water for drought tolerant crops?

APPENDIX 3: Key informant guide

Interview guide for World Vision Bolamba ADP

1) What was the total cost of solar PV equipment?
2) Do you think solar PV energy for small scale irrigation is a viable solution?
3) What are the lessons learned so far since the establishment of the scheme?
4) Can this technology be replicated in other areas and what would be the major impediments for the adoption of this energy?
5) Can this renewable technology be adopted for drought tolerant crops in some areas in the district with low underground water levels?
6) What are socio- economic and environmental impacts of solar PV energy?
7) Do you think sustainable energy access to irrigation schemes is getting enough attention from the government?
8) What do you think could be done by the government to increase uptake of solar PV energy on irrigation in rural areas of Zimbabwe.
9) What other potentials do solar PV hold in enhancing food security?

Interview guide for Irrigation Management Committee

1) How many farmers are in the irrigation? What is the total number of males and females?
2) Who funded the initial establishment of solar PV system for the irrigation?
3) How has this type of energy helped farmers to be food secure?
4) Who operates solar PV pumps at Pelele irrigation scheme? How long does the pumps operate during the day?
5) What are total crop yields for the last 2 years?
6) How much is contributed by farmers for repairs and maintenance?
7) What are the challenges faced by farmers in operating solar PV systems?
8) What is total depth of the borehole?

Interview guide for ward 12 Agritex Officer, Councillor and Pelele village head

1) How has this type of energy helped communities to be food secure?

2) Can this technology be replicated in other areas and what would be the major impediments for the adoption of this energy?

3) Do you think sustainable energy access to irrigation schemes is getting enough attention from the government?

4) Can this renewable technology be adopted for drought tolerant crops in some areas in the district with low underground water levels?

5) What is your comment on water abstraction levels at Pelele Irrigation scheme? What do you think could be done to ensure irrigation efficiency so that abstraction rate does not exceed the rate of underground recharge?

6) Can farmers in other villages afford the cost of solar PV without NGOs support?

Interview guide for ZERA

1) What are current prices of solar panels in Zimbabwe?

2) Is solar energy affordable, accessible and environmental acceptable compared to other sources of energy? Explain.

3) What are current fuel prices in Zimbabwe?

APPENDIX 4: Field observation guide

1) How many hours is the pump switched on?
2) How many solar panels are mounted?
3) Cleanness of solar panels
4) Are solar panels fenced?
5) Back of panel information on wattage and voltage
6) Components of solar pumping system
7) Size of the pump in terms of energy requirement
8) Depth in metres of the borehole(Pumping head)
9) Water output levels per hour
10) Observation of different crops grown
11) Are there any water conservation techniques at the irrigation and the method of irrigation?
12) General state of irrigation
13) Any record keeping at the scheme on total crop yield?

APPENDIX 5 : Photovoltaic data, water data and general irrigation information for Pelele solar powered irrigation scheme.

Number of solar panels	9
Size of each solar panel	235W
Output voltage of each solar panel	37.4 volts
Connection of solar panels	Series
Size of solar pump in Kw	1.5kW
Input voltage	220 volts
Water source	Borehole
Total dynamic head	47 metres
Water demand- observed in September	30m³ or 30 000Litres
Pump specifications on flow rate	10m³/hour
Maximum pump total dynamic head	72metres
Water tank size	10 000 Litres
Irrigation system	Drip irrigation system

Source: Research data 2015